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Crack Sealing in Flexible Pavements: A Life Cycle Cost Analysis

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Abstract: Pavement cracks are usually sealed to prevent water from entering into base course layers. Experience suggests that water, present in pavement layers, hastens pavement deterioration and increases rehabilitation costs. Initially, the Ministry of Transportation, Ontario (MTO) experienced only limited success in sealing cracks because of the use of inappropriate materials and installation procedures. This setback, at the initial stages of development in crack sealing, raised questions concerning the effectiveness of crack sealing in reducing the rate of pavement deterioration.

In the 1970's and 1980's, MTO carried out several field studies to develop an effective crack sealing procedure and to study the influence of crack sealing on pavement distress and performance. As well, the cost-effectiveness of this treatment was investigated. The results of the studies indicate that sealing cracks is a viable and cost-effecive preventive maintenance treatment which can extend the service life of asphalt pavements by 2–5 years. However, for optimum benefits, the crack sealing program must be implemented according to the guidelines proposed in this paper. The guidelines provide a basis for the selection of suitable pavements and cracks, sealant materials, and application procedures.

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Key Words: crack sealing, cost-effectiveness, life-cycle cost analysis, present worth costs, sealant materials, pavement distress

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Executive Summary

Purpose

This report recounts MTO's experience in developing an effective crack sealing procedure for flexible and composite pavements. The main purpose of this report is to provide a better insight into the nature of the problems and the potential benefits associated with the crack sealing operation. As well, a basis for determining the cost-effectiveness of crack sealing treatment to extend pavement service life is presented.

Problem

Crack sealing treatment is gaining more and more attention as a preventive pavement-maintenance procedure. Maintenance engineers and supervisors are often involved in making decisions as to why, when, and how to seal cracks in flexible pavements. Most of them have to make decisions based on their experience and judgment. Sometimes, this leads to unfavourable results. Three factors contribute to this situation: first, the improper timing of applications; second, selection of unsuitable pavements, and third, inappropriate application procedures. Thus, proper procedures for effective crack sealing and guidelines for selecting suitable pavements need to be developed.

Background

Traditionally, MTO sealed cracks by spraying rapid-setting emulsions on the cracked pavement surface and covering them with dry sand or chips. This method of sealing cracks was not effective in preventing water from entering the pavement. Field investigation revealed that sufficient emulsions were not retained within the cracked width to cover the additional opening during the winter. Consequently, MTO began to rout and seal cracks using the procedures established for Portland Cement Concrete (PCC).

Initial experience in routing and sealing cracks was not successful because the procedures and materials used in PCC pavement were not adequate to provide the additional extension needed in asphalt pavements. Crack width in asphalt pavements increases twice as that in PCC pavements. Thus, two requirements need to be met to improve the performance: first, the sealant materials must be more adhesive and elastic; second, rout width must be adequate to retain the required width of the material to provide the additional extension.

In the early 80's, MTO conducted several field studies to assess the consequences of not sealing cracks and to develop an effective crack sealing technique to ensure good bonding. Based on these studies, proper guidelines were developed with respect to the selection of materials, crack preparation, equipment and application procedures for crack sealing.

Province-wide study

In 1986, MTO conducted a comprehensive study on routing and sealing covering pavement sections from different climatic and environmental conditions across Ontario. The purpose of this study was to acquire statistically based data for objective assessment of the effect of rout configuration on sealant bond failures, the influence of crack sealing on performance, and the benefits in terms of extended pavement life of this treatment. As well, a life-cycle cost analysis was carried out subsequently to determine the cost-effectiveness of this treatment.

Results of the studies

The results of the studies indicate that rout and crack seal treatment is a cost-effective preventive maintenance procedure which can increase the service life of a pavement by 2–5 years. For optimum benefits, crack sealing programs must be implemented using established guidelines with respect to selection of suitable pavements, type of cracks, materials and application procedures.

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1/ Introduction

Over the past two decades, the Ministry of Transportation of Ontario (MTO) has been actively involved in the investigation of crack sealing operations as viable maintenance treatments for flexible pavements. This paper describes the Ministry's experience in developing effective crack sealing procedures to prolong the service life of pavements in Ontario. It also provides a focus for determining whether or not crack sealing in flexible pavements is a worthwhile maintenance procedure.

In the beginning, MTO experienced limited success in the performance of sealant materials to meet the desired objectives, due to the use of inappropriate materials and installation procedures. As a result, some engineers debated the merits of sealing cracks, particularly in flexible pavements. However, despite the initial setback, the Ministry continued its effort to develop and improve the method of sealing cracks, because overwhelming evidence indicates that cracks not treated effectively will lead to premature failure of pavements.

Pavement cracks, if not sealed, allow water and saline solution to permeate (during the winter) the base course layers. A field investigation [1] revealed that water, present in pavement layers, leads to accelerated deterioration, loss of structural strength and functional serviceability, increased maintenance cost, and decreased useful life. This created the need to develop an effective maintenance treatment to prevent water from entering into pavement cracks and to prolong pavement life. With current technology, sealing cracks is no longer an ineffective task, but rather a viable preventive maintenance technique which can increase greatly the life expectancy of asphalt pavement.

Based on field observations and experience gained in experimental studies conducted during the past 20 years, this paper will cover the following topics: background information, consequences of not sealing cracks, effects of crack sealing on pavement distress and service life, and life-cycle cost analysis of crack sealing.

2/ Background

Traditionally, MTO sealed cracks by spraying rapid-setting type emulsions (RS-1) and by covering them with dry sand or chips to prevent tracking by traffic [2]. The performance of this treatment in most cases is unsatisfactory due to the following reasons.

During the winter, longitudinal cracks open up to 4 mm, and close almost completely in the summer. On the other hand, transverse cracks open up to 10 mm during the winter and close partially in the summer, leaving about a 10% permanent residual crack opening [3]. This residual transverse crack opening increases with time. Crack sealing is usually carried out in the summer or early fall; during this time, cracks are normally in the closed position. As a result, no room existed for emulsions to penetrate into the longitudinal cracks, and very little room remained in the transverse cracks. Even if the emulsion managed to enter into the transverse cracks, there was no provision for the material to extend up to the new crack width opening, without rupture, when the pavement contracted at lower temperatures.

Consequently, in the early 1970's, MTO began to seal cracks in asphalt pavements using the method commonly known as rout and seal. Initially, MTO used the sealant materials and the installation procedures (which include the use of 19 x 19 mm rout size) established for Portland Cement Concrete (PCC) pavements. The results of the early rout and seal program were not successful, mainly because the sealant characteristics required for joints in PCC pavements were unsuitable for cracks in asphalt pavements. For instance, at low temperatures, the crack opening width in asphalt pavements is twice that in PCC pavements. Hence, materials for sealing cracks in asphalt pavements need to be more adhesive, resilient, and flexible. This setback, at the early stage of development, raised concerns regarding the effectiveness of this treatment in reducing the rate of pavement deterioration. To address these concerns, MTO carried out investigations in four major areas of importance, namely: 1) consequences of not sealing cracks, 2) effective crack sealing procedures, 3) benefits in terms of extended service life, and 4) life-cycle cost analysis.

2.1/ Consequences of Not Sealing Cracks

In the early eighties, MTO conducted several field studies to assess the consequences of not sealing cracks in flexible pavements [1]. These studies were done while the search for an effective crack sealing treatment continued. Fifteen transverse cracks, from highways representing various construction and service histories, were identified and pavement samples from each crack location were taken by

trenching and coring (Figures 1 and 2). From these samples the following observations were made:

- In most cases, severe disintegration was observed at the bottom of the asphalt layers, as seen in Figure 3, which shows the reduction in pavement thickness from 300 mm to almost 150 mm. This damage was due to the pumping action of water present in the pavement layers. Pumping took place when water was pushed towards the crack by the downward movement of the upstream slab, under the approaching traffic load (Figure 4). When the wheel load moved on to the downstream slab, the process was reversed. During this process the bituminous materials, from the edges of the vertical cracked faces, were removed by stripping, which resulted in the reduction of asphalt concrete thickness. For highways with low traffic volumes, the damage was more pronounced in the upstream slab; for highways with heavy traffic volumes, the damage was done on both sides. In general, relatively more damage was observed in the upstream side of the crack than in the downstream side.

- Pavements with damage at the bottom of the asphalt concrete layer often demand special treatment at the time of rehabilitation. This treatment usually involves cutting the pavement slab along the crack to a width determined by the extent of the damage (usually 1 m), and replacing it with a well compacted hot mix.

- In addition, water present in pavement causes a) the upheaval of the pavement surface (lipping, Figure 5) due to the swelling of saturated granular base materials underneath the surface because of frost action, and b) depression at the cracked surface due to thawing (cupping, Figure 6).

Therefore the consequences of not sealing cracks will be: 1) increased rehabilitation cost, 2) loss of pavement service life, and 3) increased vehicle user costs.

2.2/ In Search of Effective Crack Treatment

In 1980, after the initial setback, attributed to the use of improper materials and installation techniques, MTO initiated a pilot field trial on Hwy 69 in the Huntsville District [4]. The trial evaluated the performance of approved and non-approved sealant materials. In addition, this experience was expected to provide a basis for developing effective crack sealing procedures.

A total of 19 trial sections, each 450 m long, were installed on a 9 km stretch of Hwy 69 between Port Severn and Mactier, in northern Ontario. At this location, the mean temperature during the winter was

-10 °C, with the lowest recorded temperature being -30 °C . The pavement was 15 years old, with a total crack length of approximately 1000 m on each section. Table 1 provides a summary of the materials and the installation methods used in the trial sections. During installation, numerous problems surfaced mainly because of the use of improvised equipment by an ill-trained crew. The problems were further aggravated by the unfavourable weather conditions. Consequently, the sealant materials performed poorly after one winter season. Based on the experience gained from these trial sections, the following recommendations were made for future installation of test sections:

- cracks must be completely dry and clean;
- a router should be capable of following an exact crack path;
- sealing must be done immediately after cleaning the cracks; and
- the overfill and strike off method should be used.

Following these recommendations, an additional 14 test sections were installed in 1981 on the same highway, northward from the end of the 1980 trials. All cracks were routed to 19 x 19 mm. Back pack blowers were used to clean all cracks, except for one, where a Prismo hot compressed air (HCA) lance was used. Table 2 provides a summary of the materials and the methods used.

In addition, another test site was installed on Hwy 17, in the Ottawa district, to determine the effect of crack sealing on crack growth [1]. This test site consisted of 3 sections, 2 treated sections, with a control section located in the middle, each 1 km long.

These observations were made from the studies:

a) the tenant router was incapable of routing the meandering cracks;

b) the routed grooves could be kept clean by maintaining the distance of not more than 30 m between the blower and the kettle during application;

c) materials which met the ASTM D3405 requirements performed the best at cold temperatures;

d) the HCA tended to scorch crack edges;

e) the crack sealing treatment minimized secondary crack growth [1]; and

f) the average cost of the rout seal operation was $1.50 per metre.

Subsequently, two additional pilot projects were initiated in Ontario [4,5] between 1982-83, to validate the above findings and also to determine the effective rout configuration. As well, the projects tried to develop efficient work procedures for co-ordinating different activities. Based on the above studies, the following guidelines were developed for effective crack sealing operations.

1) **Routing**

Use a rout size of 40 mm in width and 10 mm in depth for the following reasons:

- it provides a large adhesive surface area at the bottom which reduces the induced strain on the vertical crack faces and promotes good bonding;
- it has a shape factor of 4:1 which improves the ability of the sealant material to extend at low temperatures and to minimize bond failure; and
- it increases the productivity of the routing machine.

2) **Equipment**

- For routing, use Crafco and Marathon mechanical routers, as they are the most efficient and productive routers currently available [5].
- For cleaning, use a Hot-Compressed-Air Lance (HCA) which can produce heated air to 700°C, under a pressure of 630 kPa [5].
- For applying sealants, use a double-jacketed oil kettle equipped with a dispensing wand, and capable of providing indirect heating and constant agitation. Ensure that the maximum distance between the HCA and the kettle does not exceed 25 m [5].

3) **Materials**

- Use hot rubberized asphalts meeting the ASTM D 3405 requirements for province-wide application. However, materials meeting the ASTM D 1190 requirements are allowed in southern Ontario which usually experiences moderate temperatures during the winter.

The results of the pilot studies conducted between 1980-1983 increased confidence in the use of crack sealing treatments and opened the way for further province-wide field investigations to assess the overall benefits. A brief description of the trial sections and the test results are presented in the subsequent sections.

3/ A Comprehensive Province-Wide Study

In 1986, a comprehensive study, covering different climatic and environmental conditions, was carried out across Ontario [6]. The main purpose of the study was to acquire statistically based data for objective assessment of the effect of rout configuration on sealant bond failures, the influence of crack sealing on crack growth, the benefits of crack sealing treatment, and the cost-effectiveness of this treatment.

3.1/ Pavement Test Sites

This program entailed the selection of a range of pavement sections of various ages, thicknesses, and traffic. A total of 37 test sites were selected, each having 5 sections 150 m long. The cracks, in all but the middle sections, were routed and sealed (Figure 6) using the methods previously recommended. For a comparative evaluation, the cracks in the middle section were left untreated.

A rout configuration 40 mm wide and 10 mm deep was used for the first and third sections, in all test sites. A rout size of 12 x 12 mm was used for the second and the fifth sections, selected from 6 test sites located in the southern region only. The rest of the sections, from test sites located in all the regions, used 19 x 19 mm. It was felt that use of a 12 x 12 mm rout size in cold regions would not provide the required extension.

The materials used for crack sealing were Hydrotech 6165, Hydrotech 6160, and Tremco 205 which were supplied by the approved designated sources.

3.2/ Results

3.2.1/ Effective Rout Size

The effect of rout size on sealant failure was assessed by the percentage of bond failure. Figures 8 and 9 show that a 40 x 10 mm routing has a better performance record than the others. Further, it was confirmed that this performance difference was statistically significant [7].

3.2.2/ Effect on Crack Growth

The test sites were crack mapped every year during the winter, to assess the crack growth in linear metres. The statistical analyses confirmed that the treated sections, in general, performed better than the control sections [7]. These findings are demonstrated in Figures 10 and 11 which compare the crack growth in both the treated and the control sections.

However, some test sites indicated that crack sealing had no effect on crack growth. Further investigation revealed that crack sealing treatments will be effective only for certain types of pavements. For instance, pavements with extensive cracking will not benefit by such treatment. Thus, suitable guidelines need to be developed for selecting pavements and for timing the crack sealing treatment.

3.2.3/ Effect on Pavement Life

Based on the field data obtained during the four year monitoring period, average performance curves were drawn for both treated and control sections, as shown in Figure 12. The computations involved in developing performance curves were discussed in detail in Reference [7]. The performance curves indicate that crack treatment can extend pavement life by 2-5 years, depending on the original pavement condition, environment, and traffic. Further analysis confirmed that the observed difference in performance, measured in terms of Pavement Condition Index (PCI), was statistically significant.

4/ Life-Cycle Cost Analysis

A number of methods are available to evaluate the cost-effectiveness of alternative pavement maintenance treatment strategies. The selection of the most appropriate method depends on many factors. In this case, the cost-effectiveness method is considered suitable because the benefits of alternative treatments can be measured in nonmonetary terms. The expenditures in this method are reduced to present worth costs, and the benefits are assessed in terms of effectiveness, as described later. The procedures involved in the cost-effectiveness method are described as follows.

4.1/ Economic Factors

The major economic factors considered in the analysis are: timing of rehabilitation, cost of rehabilitation in terms of $/km, analysis period, discount rate, present worth costs, traffic volume, terminal value, and PCI before and after rehabilitation.

Routine maintenance costs, which are probably identical for both sections, are not included in the analysis, because of the lack of reliable information. The following sections provide a brief description of the economic factors listed above.

Timing of Rehabilitation

This refers to the year the rehabilitation is expected to occur.

Cost of Rehabilitation

This reflects the anticipated cost of rehabilitation for the program year and is expressed in terms of thousands of dollars/kilometre for all lanes.

Analysis Period

This is defined as the number of years to be considered in the life-cycle cost analysis. A period of 30 years was assumed in this analysis.

Discount Rate

A discount rate is used to reduce future expected costs or benefits to present day terms. Sometimes the value of the discount rate is chosen to coincide with the agency rate of borrowing money. The effective discount rate was calculated as follows:

$$D = \{(1 + i) / (1 + f)\} - 1$$

where: D = discount rate
i = prime interest rate (decimal)
f = inflation rate (decimal)

For example, a prime rate interest of 10% and 5% of inflation would give a discount rate of

$$D = [(1 + 0.1) / (1 + .05)] - 1$$
$$= 0.047 \text{ or } 5\%$$

In this analysis a discount rate of 5% is used.

Present Worth Costs

The present worth costs are calculated as follows:

$$C_{pw} = C / (1 + D)^n$$

where: C_{pw} = present worth rehabilitation costs ($)
D = discount rate
n = implementation year
C = rehabilitation cost on the implementation year.

Traffic Volume

Traffic volume is measured in terms of annual average daily traffic volume (AADT) in both directions, at the start of the analysis period.

Pavement Condition Index

The Pavement Condition Index (PCI) is a measure of pavement serviceability which rates the condition of pavement on a scale from 0 to 100, representing the range from an extremely poor (impossible) condition to a perfect condition. Serviceability decreases with time and once the PCI of a pavement reaches the minimum acceptable level, the pavement should be rehabilitated. The choice of the PCI

level triggering rehabilitation depends on the type and the purpose of the pavement section. For example, a value of 50 or 55 is usually assigned for pavements carrying a traffic volume less than 2000 AADT, and 60 for AADT which is greater than 2000. To calculate effectiveness, as defined later in this report, the input data for the life-cycle cost analysis requires the PCI values both before and after rehabilitation.

Terminal Value

This refers to the remaining useful life of the pavement, after the end of the analysis period. The terminal value was calculated as follows:

$$TV = RC \times RSL / LIFE$$

where: TV = terminal value ($)
RC = the cost of last rehabilitation or treatment before analysis period ($)
RSL = remaining service life of treatment beyond analysis period (years)
LIFE = service life of last rehabilitation treatment (years)

4.2/ Analysis Procedure

In life-cycle cost analysis, the key issue is the assessment of pavement service lives after construction and subsequent major rehabilitation treatments within the analysis period. Different methods exist to predict pavement performance. The Ontario method (OPAC), for example, developed by Jung et al [8] uses mathematical modelling to assess the loss in PCI due to both traffic and environment. The loss due to traffic, P_I, is expressed as a function of a number of equivalent standard axial load applications, whereas the loss due to the environment, P_E, is expressed as a function of time (years). Thus, PCI(t) at given time, t, is calculated by the following equation:

$$PCI(t) = PCI(i) - P_I - P_E$$

where: PCI(i) = the pavement condition index immediately after construction or rehabilitation.

A mathematical model to predict performance is useful for economic evaluation of alternative pavement design strategies, involving various combinations of materials, layer thicknesses, traffic, and rehabilitation treatment. However, performance prediction models developed this way need to be calibrated using the known pavement performance history.

In this study, several highway projects in Ontario, with known performance histories over the past 12 years, were reviewed for tentative calibration of the predictive model and selection of the most

suitable model for subsequent cost-effectiveness analysis of the crack sealing treatment. Figure 13 compares the actual and predicted performance of a typical two-lane section highway (Hwy. 80). In the life-cycle cost analysis, this calibrated model is used to estimate pavement service life after each major rehabilitation work within the analysis period. Figure 14 shows that the estimated service life for Hwy 80 after a major rehabilitation is 10 years.

A computer program (PRLEAM) was developed by the University of Waterloo and MTO [9] to carry out the life-cycle cost analysis of pavement rehabilitation treatments. The program assumes that the PCI varies linearly with time (year) within the estimated service life. Generally speaking, this assumption is quite reasonable, particularly for evaluating different maintenance treatments since the shape of the performance curve is not likely to affect the final outcome of the results. However, based on the data acquired over the past 12 years, the performance curve of the pavement under investigation was found to be curvilinear, as shown in Figure 13. Hence, it is assumed that that the subsequent performance curves after major rehabilitation treatments would follow the same trend, under similar loading conditions. The calculations of costs and benefits are done to reflect the actual performance history of the pavement considered for the analysis. That way the results of the analysis will not only be realistic, they will also be representative of the actual prevailing conditions in the field.

4.2.1/ Life-Cycle Costs

Life-cycle costs of different rehabilitation alternatives are calculated in terms of present worth costs as follows:

$$LCC = IRC + FRC - TV$$

where: LCC = life-cycle cost
IRC = initial rehabilitation cost (IRC)
FRC = future rehabilitation cost
TV = the terminal value at the end of the analysis period.

The following section provides a brief description of the procedures used to calculate the benefits of the individual treatments.

4.2.2/ Assessment of Benefits or Effectiveness

Benefits, in terms of savings with road user costs (i.e. travel time plus vehicle operating costs) are desirable. However, these benefits are difficult to measure in monetary terms. Thus, the concept of effectiveness [10] was used, instead of benefits. The effectiveness method involves a determination of

the advantages or benefits to be gained in nonmonetary terms. In this case, the effectiveness is calculated as follows:

effectiveness = A x (AADT) x PL

where: A = area under the performance curve
AADT = average traffic volume between year 0 and end of the analysis period
PL = length of section.

The important variable in this model is the area under the performance curve which increases as performance increases. For general applications, such as priority assessment of highway rehabilitation needs for regional and provincial network integration, the area is multiplied by section length and traffic volume. However, evaluating alternative maintenance treatments for a specific highway project, traffic volume and section length will not affect the final outcome of the analysis because they remain common denominators for each alternative maintenance treatment strategy.

4.2.3/ Cost-Effectiveness Evaluation

Although the terminology used here is cost-effectiveness, the actual calculation is done through dividing the effectiveness by life-cycle costs. Hence, cost-effectiveness (C-E) is similar in concept to a benefit-cost (b/c) ratio, except that the effectiveness is measured in non-monetary terms. Therefore, evaluation of different alternative treatments is based on cost-effectiveness. For example, if the cost-effectiveness for alternative 2 is larger than for alternative 1, then the former strategy is more cost-effective.

5/ Sample Applications

5.1/ Pavement History

A two-lane section highway (Hwy. 80), 21 km long, 6.7 m wide, and located in District 1 of the southwestern region was considered for life-cycle cost analysis of rout and seal crack treatment, using a 30 year analysis period. An annual average daily traffic, in the first year after construction, was 750 vehicles, with 18% trucks. The average annual traffic growth rate was 4%. The thickness of the asphalt concrete and of the granular layers was 115 mm and 350 mm, respectively.

5.2/ Alternative Strategies

Three alternative maintenance strategies with appropriate performance histories were chosen, as shown in Figure 15. The first alternative strategy encompasses only major rehabilitation treatments, using 50 mm HL4 overlays with an estimated cost of $45,000/km at the time of construction. The second and third alternatives consider routing and sealing cracks in addition to overlays. The estimated cost of routing and sealing is $2.00/linear metre or $1500/km, assuming a total transverse crack length of 500 m (average spacing of 13 m) and a crack length of 2500 m for longitudinal cracks.

From the pavement performance record, an initial service life of 11 years was observed for Alternative 1, when the serviceability dropped to a minimum acceptable level, such as 50. A short service life of 11 years may be attributed to inadequate pavement structure. Based on the model described previously, the estimated service life after a major rehabilitation work is 10 years. From the results of a previous study [7], it is estimated that routing and sealing will extend the existing service life of pavement by 2 years for Alternative 2, and by 3 years for Alternative 3.

Routine maintenance costs are not included in the analysis because of the nonavailability of reliable data. However, it is reasonable to assume that costs of routine maintenance are the same for all three alternatives. The following sections provide sample calculations for Alternative 2's treatment.

5.3/ Present Worth Costs

Present worth costs of routing and sealing, and overlays for Alternatives 1, 2, and 3 are given in Table 3. Sample calculations for crack sealing in year 4, and overlay in year 13, using Alternative 2, are shown as follows:

For rout and seal

Year 4 C_{pw} = $21 \times 1500 / (1 + 0.05)^4$

= 25900

For rehabilitation

Year 13 C_{pw} = $21 \times 45000 / (1 + .05)^{13}$

= 501150

5.4/ Terminal Value

Table 4 provides the terminal values for all the alternatives. However, a sample calculation of the terminal value ($1000) for Alternative 2 is given as follows:

$$TV = 21(45x80 / 95 + 1.5 \times 80 / 87.5)$$
$$= 21 \times 39.26$$

$$TV_{pw} = 21 \times 39.26 / (1.05)^{30} \text{ (Present worth cost)}$$
$$= 21 \times 9.08$$
$$= 190.79$$

5.5/ Effectiveness

Effectiveness for all alternative treatments is given in Table 4. For example, effectiveness for Alternative 2 is calculated by multiplying the total area by the pavement length (21 km), and the average traffic volume, between year 0 and the end of the analysis period (1591) as shown below:

Area (PCI-Year) under each performance curve

Curve 1 = 410

Curve 2 = 397.5

Curve 3 = 202.5

Total = (410 + 397.5 + 202.5)
= 1010

Effectiveness = 1010 x 21 x 1591
= 33745.1×10^3

5.6/ Cost -Effectiveness

Cost-effectiveness for Alternative 2 is calculated by dividing the effectiveness by the total cost, minus the terminal value, as shown:

$$C.E = 33745.1 / (814.21 - 190.79)$$
$$= 54.08$$

Similarly, cost-effectiveness calculations were performed for Alternatives 1 and 3. Table 4 provides the cost-effectiveness calculation summary of three alternative maintenance strategies for Hwy 80.

The ranking, based on the cost-effectiveness factor (C-E), suggests that Alternative 3 is the most preferred, followed by Alternative 2. The ratio of C-E (1: 1.48 : 1.53) among the alternatives, shows that rout seal crack treatment can increase the cost-effectiveness by about 50%.

On the other hand, the three alternatives can be compared on the basis of cost alone. This requires discounting benefits and considering only the cost involved, in all three cases, to provide the required level of service over a period of 30 years. Table 4 indicates that the present worth cost of Alternative 1 is 37% more than the cost of Alternative 2, and 46% more than that of Alternative 3.

6/ Guidelines For Pavement Selection

Under general policy, a crack sealing program is not a corrective maintenance measure but a preventive maintenance treatment. The timing of crack sealing is a major factor that determines how cost-effective the treatment is in extending the service life of pavement. This program should be implemented before the damage is done to the pavement section. Under a limited maintenance funding program, this could be a problem. Thus, a procedure is established to identify pavements on a priority basis and schedule them over the chosen program period. For this purpose, guidelines for crack sealing were developed in two parts: a maintenance operation instruction manual for sealing cracks, and proposed flexible pavement guidelines for selecting the most suitable pavements and cracks. Guidelines for operating procedures are given in manual M-1005-A [11].

For selecting pavements and cracks suitable for rout and sealing treatment, the guidelines include: manual guidelines [12], and computer aided guidelines [13]. The former identifies types of cracks suitable for crack sealing, and the latter ranks pavements that are likely to benefit from crack sealing treatment. The ranking is done on a scale ranging from 0 to 10, with 0 being the most unsuitable and 10 being the most suitable. Under a limited funding program, pavements with the highest ranking are recommended first for crack sealing, before continuing with the next rank.

7/ Conclusion

The findings of the investigation into the effectiveness of crack sealing treatment can be summarized as follows:

1) a rout size of 40 x 10 mm promotes good bonding and is recommended;

2) consequences of not sealing cracks are increased rehabilitation cost, loss of pavement service life, and increased vehicle user costs.

3) rout and seal crack treatments can minimize the secondary crack growth and increase service life by 2-5 years;

4) the life-cycle cost analysis indicates that rout and seal crack treatment is cost effective;

5) for optimum benefits the crack sealing program must be implemented using established guidelines with respect to selection of suitable pavements, type of cracks, materials and application procedures.

References

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[3] Kingham, R. Ian "Cracking of Asphalt Concrete Pavements - A Pilot Study, Parts I, II, & III," Ontario Ministry of Transportation, 1965.

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[5] Chong G. J. and Phang, W. P. "Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions," Report PAV-87-01, Ontario Ministry of Transportation, 1987.

[6] Chong, G. J. "Rout and Seal Cracks in Flexible Pavement - A Cost-Effective Maintenance Procedure," Report PAV-89-04, Ontario Ministry of Transportation, August 1989.

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[9] Haas, R. C. J., Turray, S. and Austin, H. "Pavement Rehabilitation Life-Cycle Economic Analysis Model, Vol. 1," User Manual and Report, Prepared for the Ontario Ministry of Transportation, 1991.

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[11] "Crack Sealing: Flexible and Composite Pavements, Maintenance Operating Instruction Manual M-1005-A," Ontario Ministry of Transportation, 1984.

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[13] Hajek, J. J., Chong, G. J., Haas, R. C. J., Phang, W. A. "Knowledge Based Expert System Technology Can Benefit Pavement Maintenance," Transportation Research Board, Washington, January 1987, (Also: Report PAV-86-05, Ontario Ministry of Transportation, Dec. 1986).

Figure 1/ Subsurface deterioration at the transverse crack on Hwy 17, Ottawa

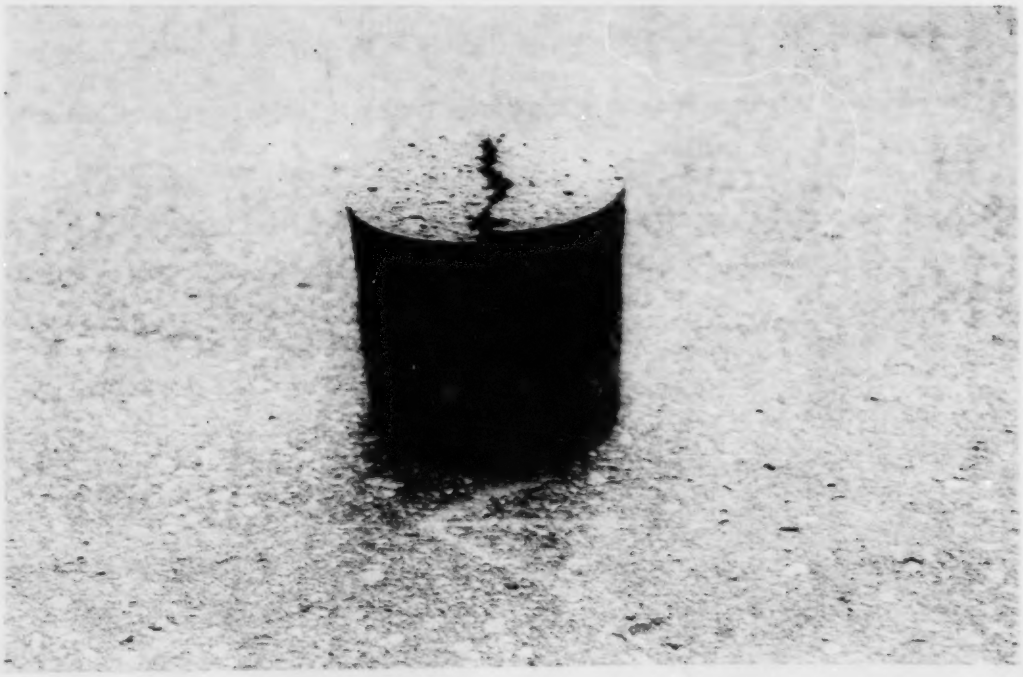


Figure 2/ Damage underneath the pavement surface - Hwy 21

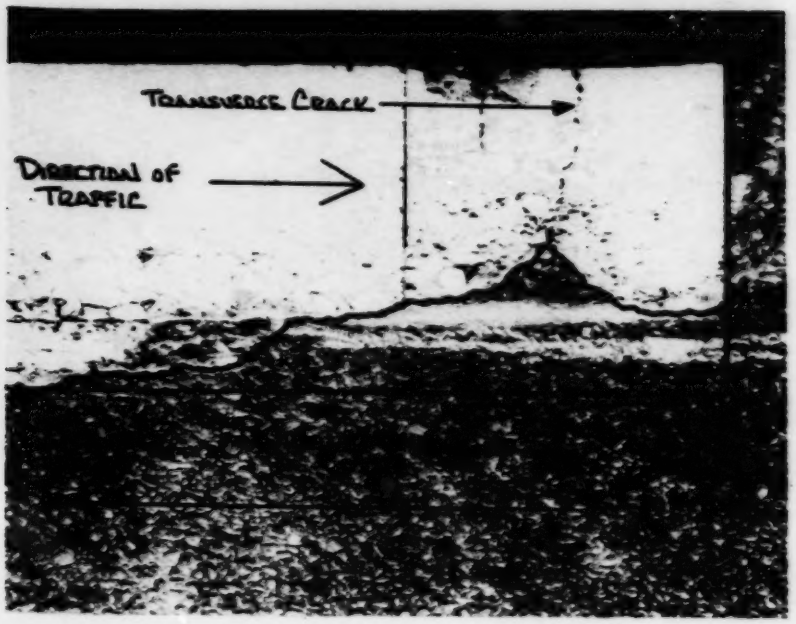


Figure 3/ Subsurface damage due to pumping action

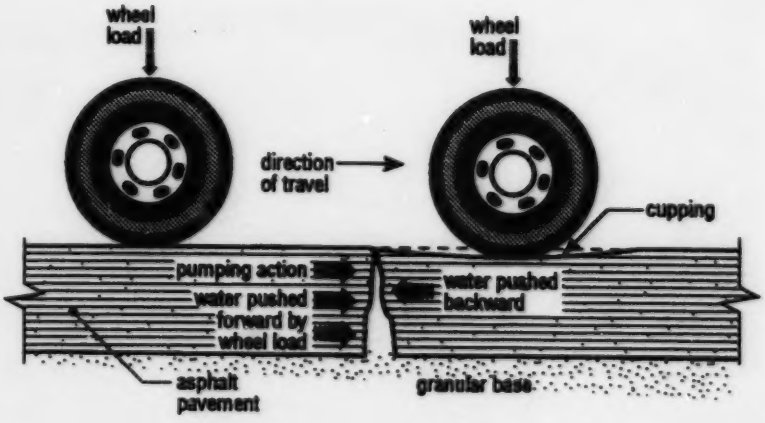
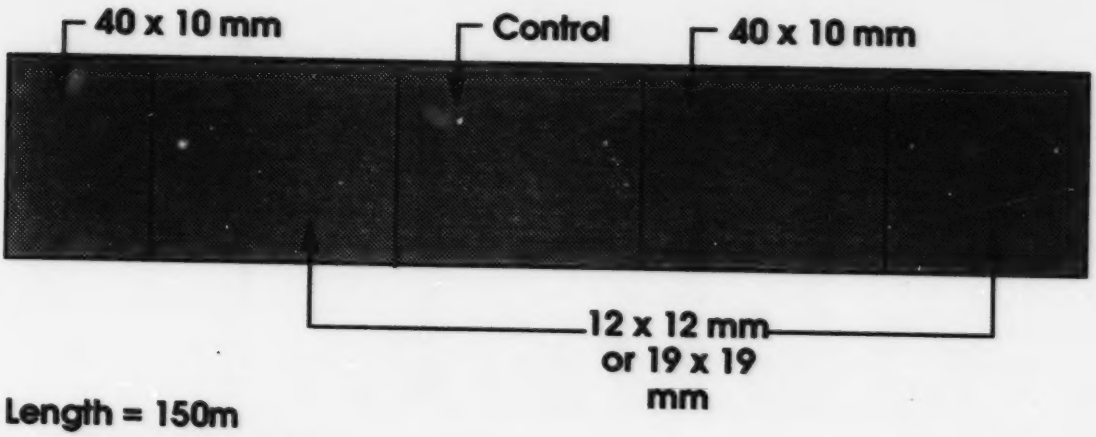


Figure 4/ Interactive effect of traffic load and water on pavement layers

Figure 5/ Lipping of asphalt pavement at transverse cracks

Figure 6/ Cupping of transverse crack



Length = 150m
No. of Test Sites = 37
No. of Test Sections/Site = 5

Figure 7/ Experimental Design

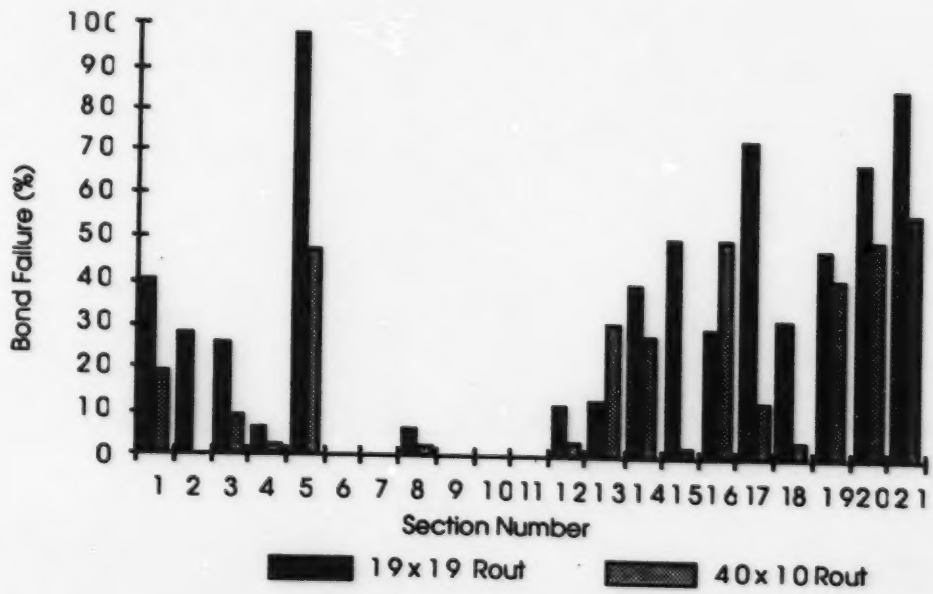


Figure 8/ Performance of different rout sizes 19 x 19 mm vs 40 x 10 mm

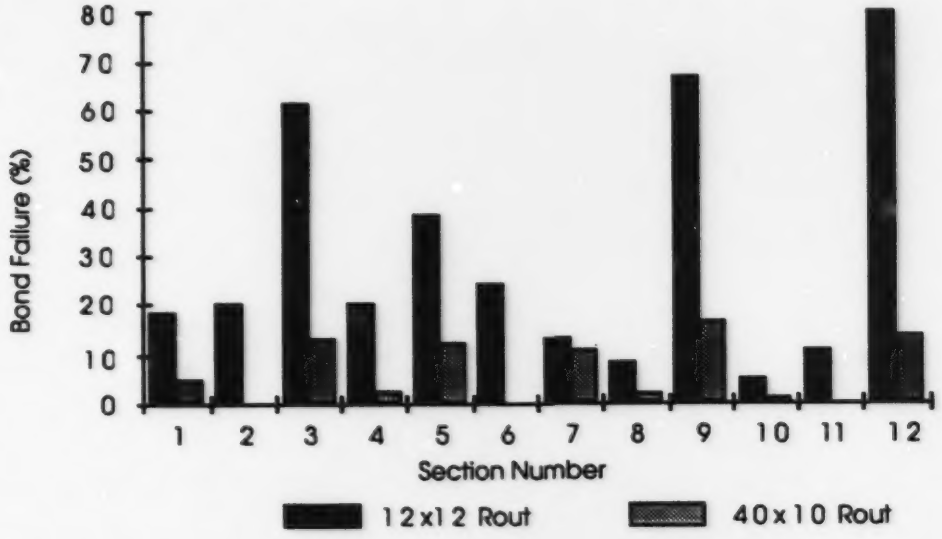


Figure 9/ Performance of different rout sizes 12 x 12 mm vs 40 x 10 mm

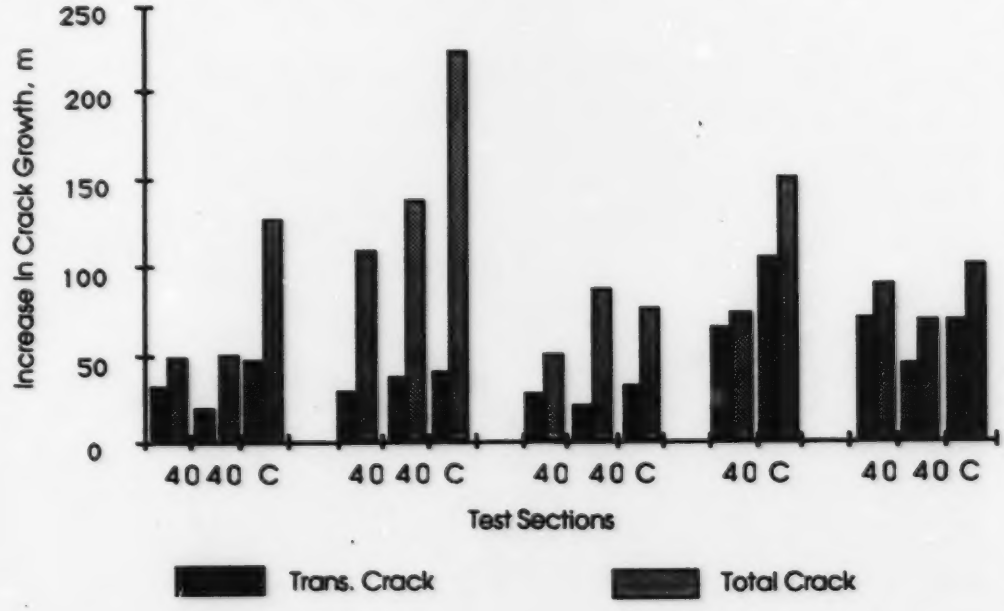


Figure 10/ Comparison of crack growth in northern region, control vs treated

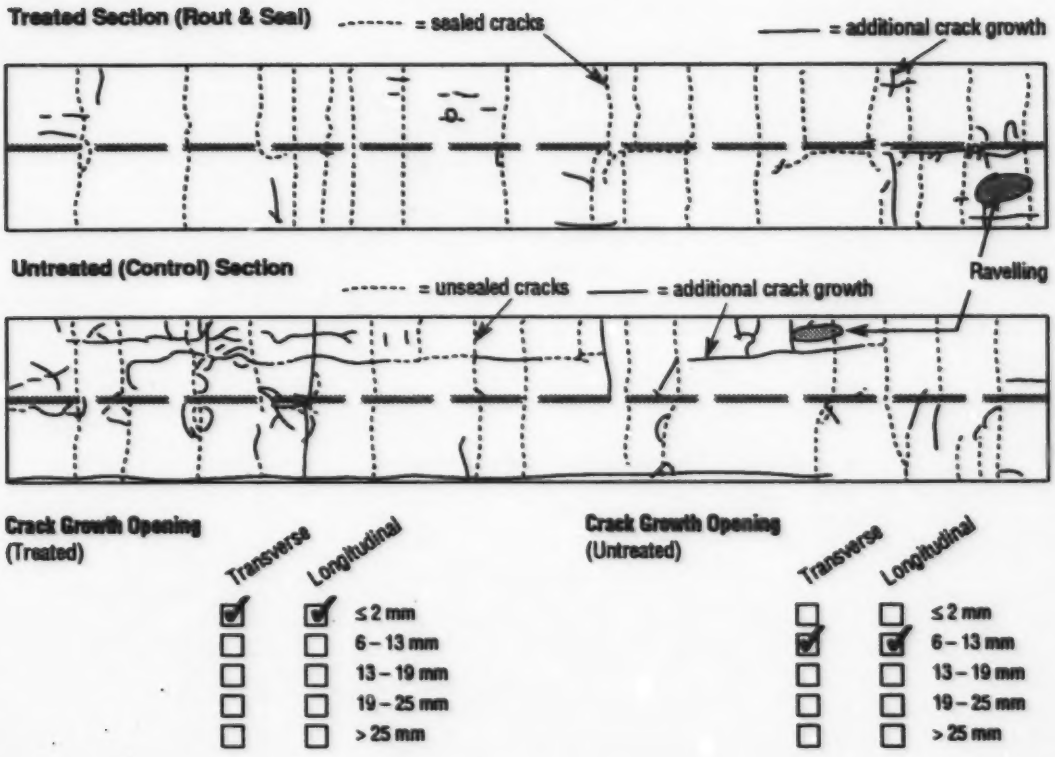


Figure 11/ Condition survey of pavement surface, Hwy. 21, from Bosanquet Sideroad #9, northerly

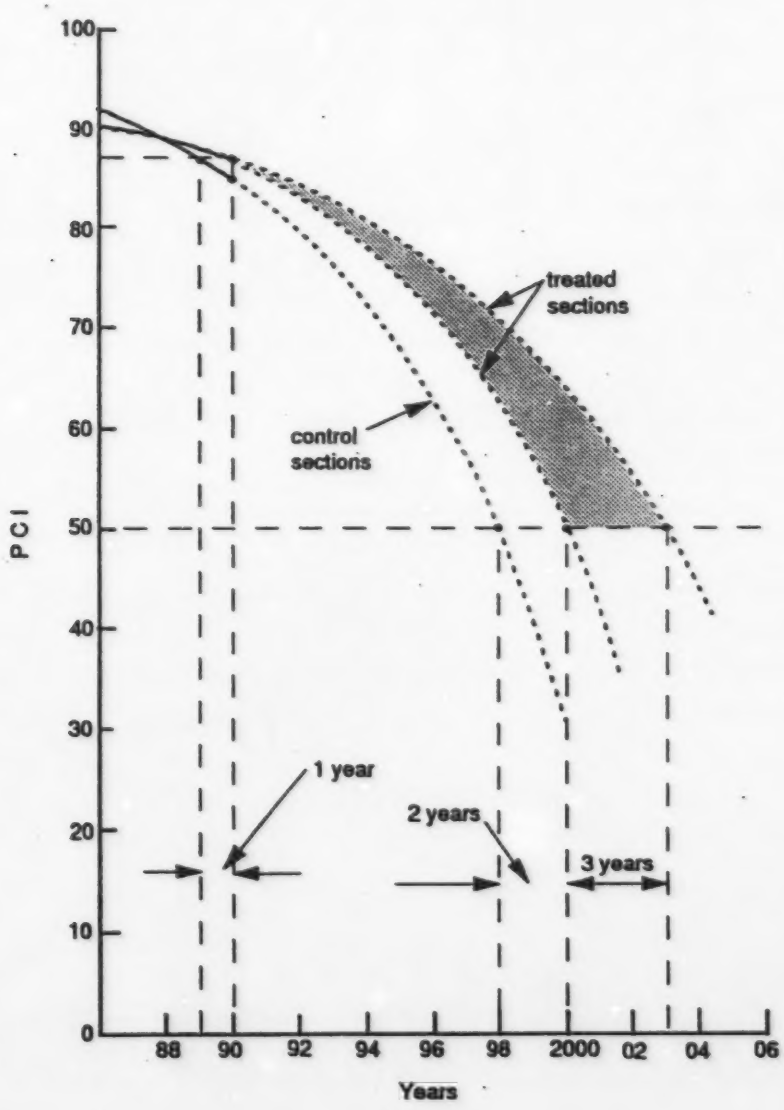


Figure 12/ Performance prediction curves, control vs treated sections

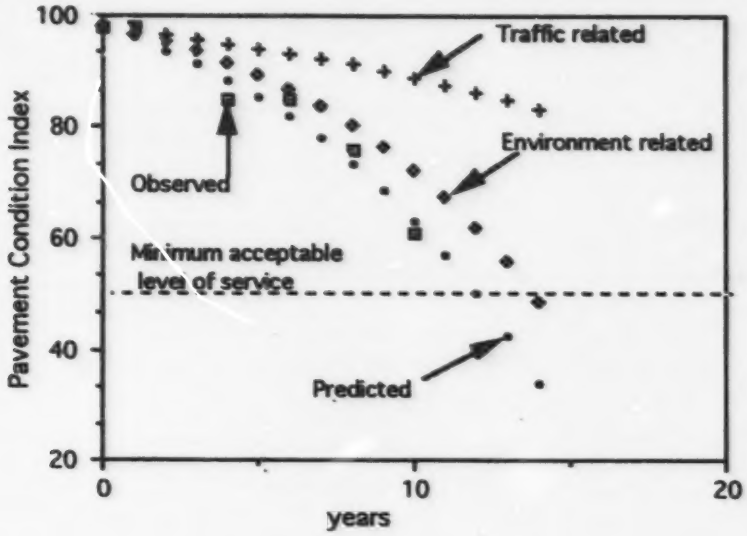


Figure 13/ Observed vs predicted performance of Hwy 80

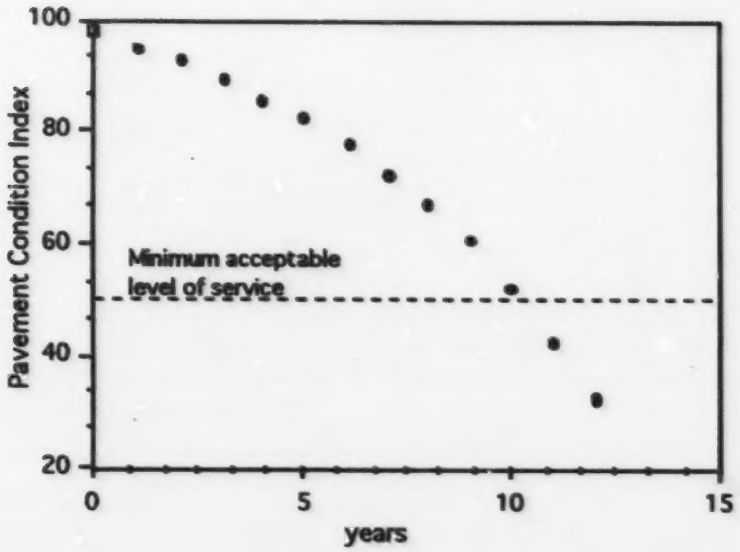


Figure 14/ Predicted performance after rehabilitation-Hwy 80

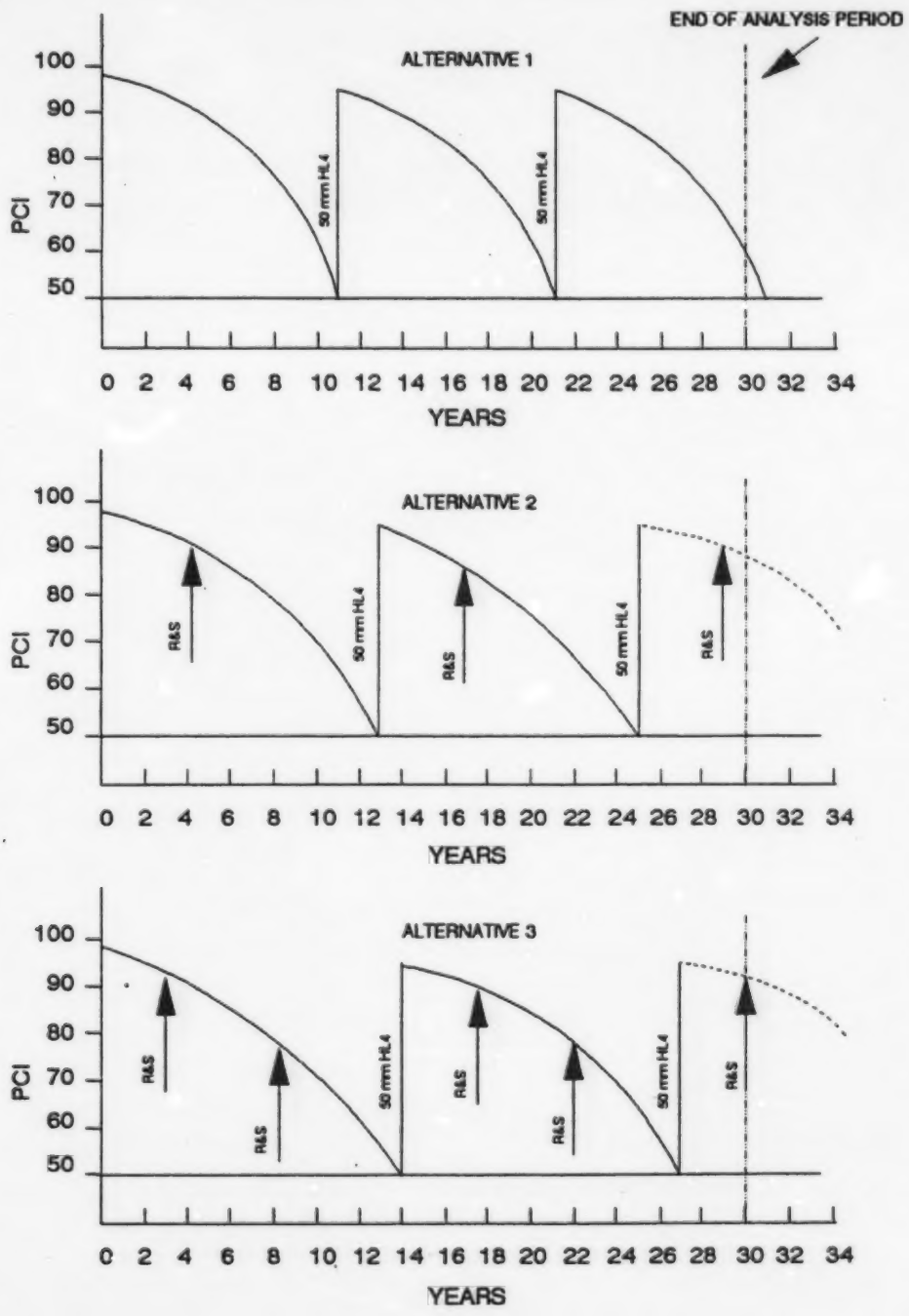


Figure 15/ Performance histories for three alternative strategies

Table 1/ Summary of materials and installation methods (1980) [4]

Trial	Manufacturer	Product	Product Description	Installation Method
7	Uniroyal	6160	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
8	Be-Ram	Supergook 21-151	Hot Applied Rubberized Asphalt	Routed/Air Blown/Overfilled and Levelled
9	Uniroyal	6165	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
10*	Flintkote	X-8032	Cold Poured Rubber Asphalt Emulsion	Routed/Air Blown/Filled Flush
11	Chevron	Rubberized Crack Filler	Cold Pour Rubber Asphalt Emulsion	Routed/Air Blown/Overfilled and Levelled
12	Meadows	164R	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
13	Flintkote	X-8006	Cold Poured Solvent Borne Rubber Asphalt	Routed/Air Blown/Filled Flush
14	Meadows	164	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
15	Flintkote	X-8013	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
16	Meadows	Sof-Seal	Hot Applied Rubberized Asphalt	Routed/Air Blown/Filled Flush
17	Crafco/Sahuaro	Overflex-MS Modified	Hot Applied Rubberized Asphalt	Routed/Air Blown/Overfilled and Levelled
18	Crafco	Overflex MS	Hot Applied Rubberized Asphalt	Routed/Air Blown/Overfilled and Levelled
19	Flintkote	X-8013	Cold Applied Two-Part Rubber Asphalt Emulsion	Routed/Air Blown/Filled Flush

* Washed out by rain and repaired with X-8013

Table 7/ Summary of materials and strike off method (1981) [4]

Trial	Manufacturer	Product	Product Description	Strike Off Method
8	Bernac	Supergook	Hot Poured Rubberized Asphalt	Flat
20	Bakelite Inc.	Flintseal 590-13	Hot Poured Rubberized Asphalt	Flat
21	Hydrotech	Sealz 6165	Hot Poured Rubberized Asphalt	Flat
22	Crafco Inc.	Roadsaver 201	Hot Poured Rubberized Asphalt	Flat
23	Hydrotech	Sealz 6160	Hot Poured Rubberized Asphalt	Shaped
24	Paraseal	Super-Seal 2065	Hot Poured Rubberized Asphalt	Flat
25	Paraseal	Ultra-Seal 2070	Hot Poured Rubberized Asphalt	Flat
26	Meadows	164R	Hot Poured Rubberized Asphalt	Flat
27	Shell Canada	Cariphalte ELT	Hot Poured Rubberized Asphalt	Shaped
28	Meadows	Sof-Seal	Hot Poured Rubberized Asphalt	Flat
29	Meadows	Hi-Spec	Hot Poured Rubberized Asphalt	Flat
30	Chevron	C.I.M.	Two Part Asphalt Extended Urethane	Flat
31	Southwestern Petroleum	Patching Compound	Cold Applied Asphaltic Mastic	Flat
32	IBIS	Prismoseal A1	Hot Poured Rubberized Asphalt	Flat
33*	Bernac	Supergook	Hot Poured Rubberized Asphalt	Flat

* Overband sealing trial only using HCA to treat crack

Table 3/ Present worth costs of treatments for Hwy 80

Alternative Strategy	Number of Rout and Seal (R&S) Treatments	Years of R&S Treatments $1000	Present Worth Cost of R&S	Number of Overlays	Years of Overlay Construction $1000	Present Worth Cost of Overlays $1000	Total Present Worth Costs
1	0	0	0	2	11	552.5	
					21	339.2	891.7
2	2	4	25.9	2	13	501.15	
		7	13.74		26	265.77	814.21
		29	7.65				
3	4	3	27.21	2	14	477.28	
		8	21.32		28	241.06	789.66
		17	13.74				
		22	10.77				
		30	7.28				

Cost of overlay is $45000/tonne at time of construction

Cost of rout and seal is $1500/km at time of construction

Table 4/ Summary of cost-effectiveness calculations

Description of Item	Alternative Strategies		
	1	2	3
Total present worth ($1000.00)	891.7	814.21	798.66
Terminal value ($1000.00)	36.44	190.79	214.43
Life-Cycle Costs	855.26	623.95	584.23
Effectiveness (1000)	31281	33745	32742
Cost-Effectiveness Factor	36.57	54.08	56.04
Cost-Effectiveness Ratio	1	1.48	1.53